BARKHAUSEN — KURZ OSCILLATIONS WITHIN CAVITY RESONATORS

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by

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PREFACE

The work described herein was done at the United States Naval Postgraduate School and at Varian Associates, Palo Alto, California. The purpose of this paper was to investigate the application of the Barkhausen-Kurz theory of oscillation to a microwave tube.

The writer wishes to acknowledge, with appreciation, the facilities made available by Varian Associates and the many helpful suggestions of Doctor Malcolm Bauer.

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ABSTRACT

This paper describes in detail the development, manufacture and tests of a microwave oscillator based on the Barkhausen-Kurz theory of positive grid oscillations.

The basic idea was conceived in June 1954 and all work through the preliminary testing of the external cavity prototype was carried out at the United States Naval Postgraduate School. A portion of the industrial term was utilized in the manafacture and test of an internal cavity tube designed to operate in the "K" band.

HISTORY

The technology of positive grid tubes dates from 1920 when Barkhausen and Kurz [1] published the results of certain experiments with high-power triodes. They discovered the existence of strong oscillations of very high frequency which are maintained so long as the grid voltage is relatively large and positive and the plate voltage zero or negative. Since this phenomenon was discovered many varied and extensive experiments have been conducted notably by Gill and Morrell [2] and others. The theory has been more than adequately explored and is presented in many texts. One of the most complete treatments is given by Sarbacher and Edson [3]. In this work is given a most comprehensive treatment of all the possible methods of connecting the resonant circuit and a detailed analytical treatment of each case. The literature reveals that triodes having cylindrical as well as planar electrodes have been utilized to perform the experiments and that lumped constants as well as Lecher wire systems have been utilized in the forming of the resonant circuits.

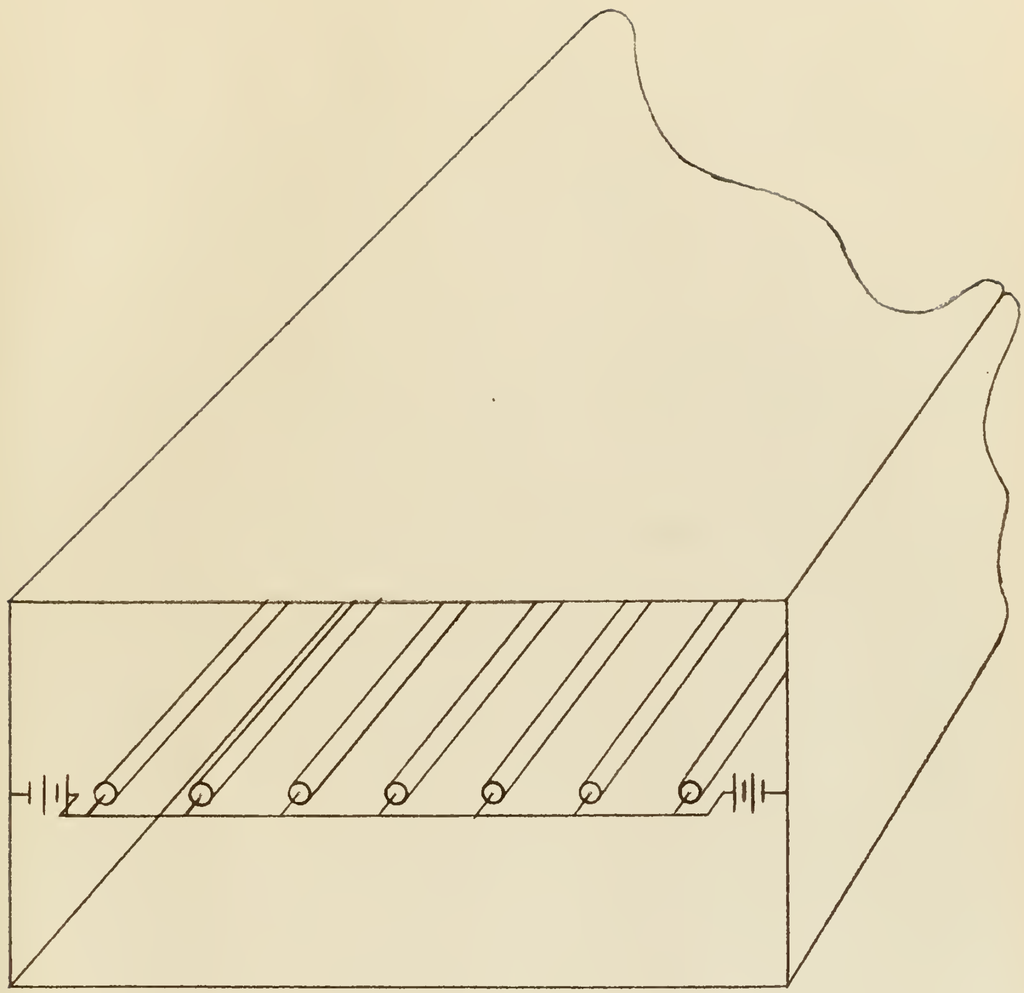
Nowhere in the literature, with the exception of a very recent work by Uenohara [4], has there been any mention of using a cavity as the resonant circuit. The obvious advantages of higher attainable values of "Q" and symmetry of such a device seem to make it desirable experiment. It is the purpose of this paper to present one such experiment.

CHAPTER I

It is proposed that the principles involved in the basic conventional positive grid oscillator may be employed to good advantage in a microwave generator to supply centimeter or millimeter waves. The basic oscillator, although proven workable, has little if any advantage over other oscillator circuits mainly because of its poor efficiency. It is proposed that this disadvantage can be overcome by proper design of a special tube consisting basically of a high "Q" cavity with an internal grid.

This tube will now be developed starting with the tuned cavity. There are several considerations in making a choice of cavity shape but for preliminary discussion purposes a rectangular cavity will be utilized. Later it will be apparent that a cylindrical shape would present additional advantages, the foremost of which are higher efficiency and simplicity of construction.

Consider now a section of rectangular waveguide boxed off at both ends and supporting a TE_{01} mode. This much of the development represents the resonant tank of the conventional positive grid oscillator. There remains to be furnished a grid and a means of placing a positive voltage on this grid. As a possible structure consider a network of straight parallel rods electrically interconnected and placed as shown in figure 1. To make the structure completely analagous to the basic circuit at this point would require that the source of grid voltage be placed between the wall of the cavity and the grid. The construction can be modified slightly at this point however and several obvious advantages accrued thereby. The grid structure will first be made in the form of an extruded "H" shape with the



Basic Cavity Resonator

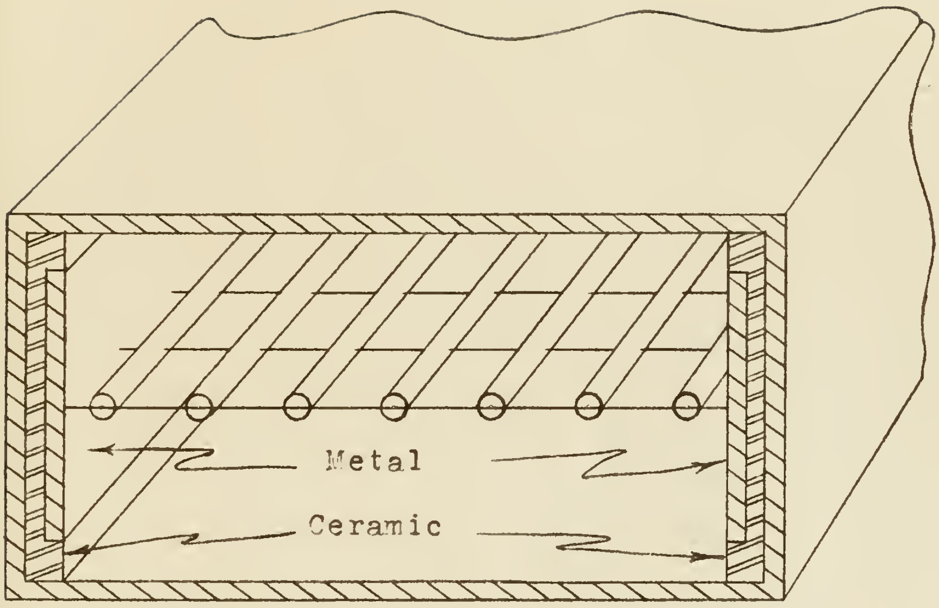
Figure 1

grid rods and their connecting network forming the cross part of the "H" and the sides of the "H" being formed by the flat parallel strips of metal parallel to, and separated from, the short edges of the waveguide. The separation to be accomplished by ceramic material to provide a capacitance between the grid structure and the sides of the tuned cavity. This arrangement, as shown in figure 2, provides:

1) A firm support for the grid.
2) A bypass for any alternating current that may be induced in the grid thereby establishing a fixed potential between the grid and the mid point of the tuned tank.
3) Direct current insulation will be provided so that the grid may be made positive with respect to the mid point of the tuned tank.

There remain only a few mechanical details to provide a system completely analogous to the basic positive grid oscillator. The positive voltage may be introduced at any place on the grid because the grid is sufficiently bypassed thereby preventing the alternating current from leaving the cavity by means of the voltage supply lead. As a means of coupling the energy from the cavity any of the conventional methods may be employed. For ease and convenience in construction, loop coupling will be employed. When attempts are made to go to the higher frequencies slot coupling directly to a guide will most likely be resorted to in order to reduce losses. The cathode, or emitting area, would be either or both of the wide faces of the guide and would extend along the length of the guide.

The basic development is now complete and as no changes in principle have been made the oscillator herein developed should at least function.



Improved Cavity Resonator

Figure 2

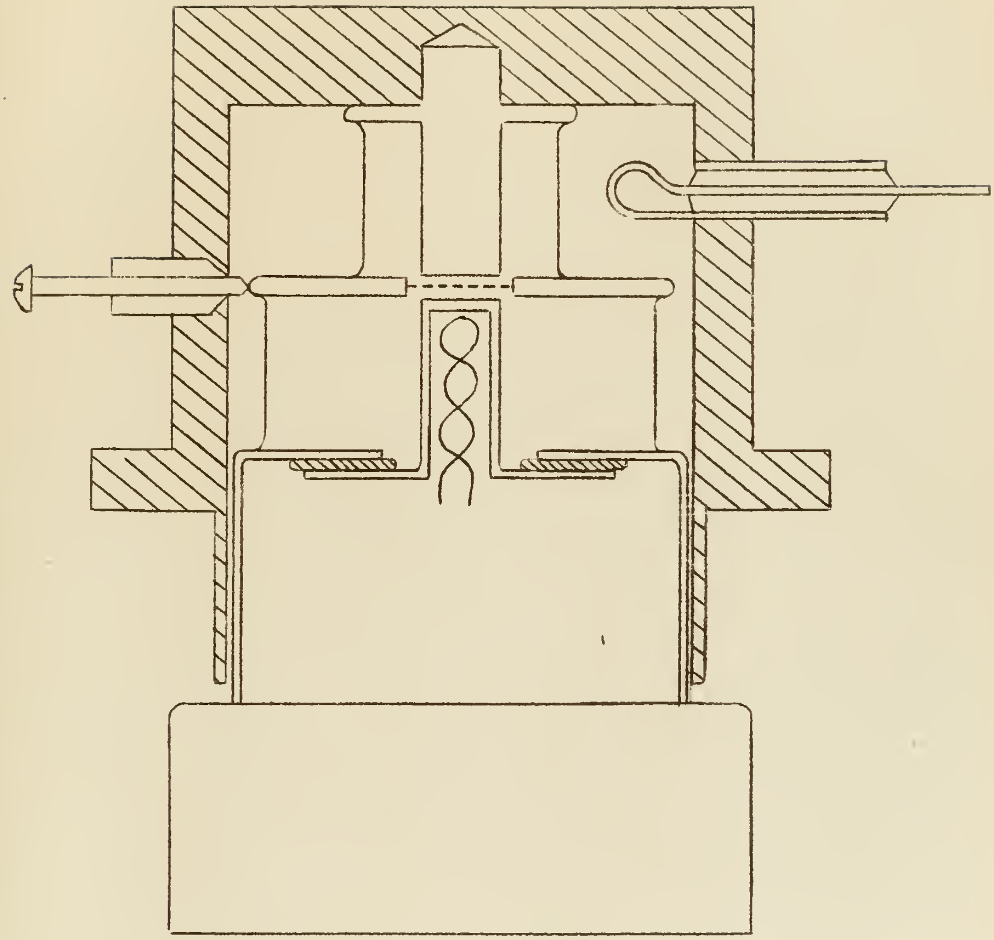
It is now proposed that such a device may be effectively used to produce microwaves of considerable power. This would require a means of grid cooling as all the electrons leaving the cathode of necessity terminate on the grid. Due to the physical dimensions involved radiation will probably be the only practical method. This plus conduction through the ceramic will be relied upon as adequate for purposes of this development.

Another device to promote efficiency will be the inclusion of some means to provide a parabolic potential distribution in the interaction space. The suggestion for this device was taken from the recent work of Uenohara [4]. In this development the parabolic potential field was essential to the functioning of his tube. In his work, however, the electron interaction with the field does not occur within the cavity. The inclusion of such a potential distribution would in theory provide a very high efficiency for once an electron crosses the cavity in the proper phase it will remain in phase with the alternating field. This will occur because the period between successive arrivals at the grid plane is independent of the distance traveled into the field. Barring its interception by the grid, the electron will continue to give up its kinetic energy to the alternating field until its amplitude of oscillation had reduced to zero. In order to minimize the interception of electrons by the grid a magnetic field could be oriented in the direction of electron motion to provide a greater opportunity for multiple transits. The strength of this field would also serve as a means of controlling the beam coupling to the cavity.

CHAPTER II

To prove the workability of such a device and also to expedite construction it was decided that a prototype would be built using a lighthouse type tube with an external cavity. It was to be expected that the efficiency of this interim device would be low for several reasons:

1) The amount of lossy material in the form of the glass walls of the tube tend to reduce the "Q" of the cavity.
2) The construction of the cathode of the lighthouse tube is such that there is incorporated therein a bypass capacitor. This construction is indicated in figure 3. This would cause no serious loss were the frequency high enough but due to the geometry of the tube the highest frequency attainable was only three kilo-megacycles. At this frequency the leakage through the mica filled slot is probably excessive.
3) The parallel grid structure of the lighthouse tube will not provide the desired parabolic potential distribution, but a linear distribution. This is precisely the type field desired for reflex klystron operation but in the desired Barkhausen-Kurz type of oscillation this will only allow the electron a few in-phase transits. There exists some doubt as to whether the oscillation obtained were of the Barkhausen or of the reflex klystron type. It was not possible to determine which of the phenomenon was actually taking place because only one mode of operation was possible. The grid spacing is so small that the



Prototype as Constructed

Figure 3

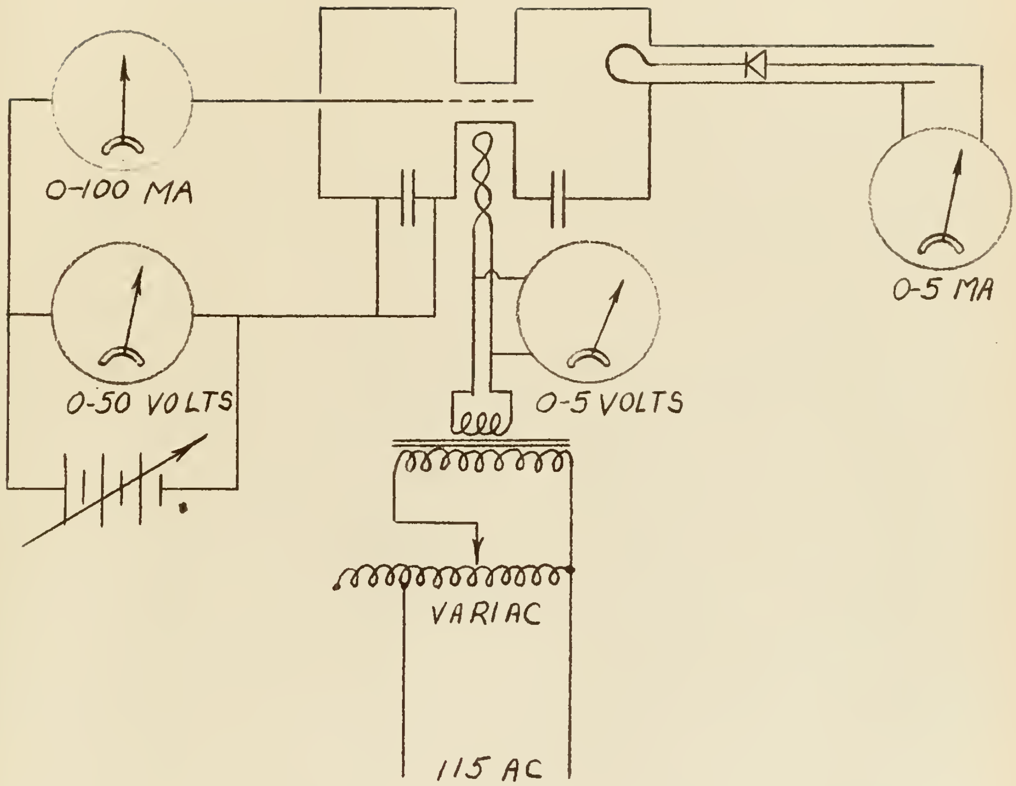
breakdown voltage occured before the second mode was reached.

Several unsuccessful cavities were constructed before a workable model was attained. Many compromises were made in the interest of simplicity of construction.

It was decided that the bypass for the grid was not vital to the operation in that the grid structure is symmetrically located and as such should remain electrically neutral in the cycle. This decision was not a fortunate one and subsequently a system for bypassing the alternating current external to the cavity was resorted to.

The oscillator as constructed is shown in figure 3. A more convenient method of placing the positive voltage on the grid would have been to use the loop. It was considered, however, that divorcing the two functions in the preliminary investigations would provide greater flexibility in that the amount of coupling could easily be adjusted by the simple expedient of rotating the loop.

Preliminary tests of the oscillator resulted in the destruction of several lighthouse tubes due primarily to the lack of adequate cooling facilities and to thermal shocks of the glass envelope when improperly cooled. The tube life was shortened considerably by the excessive grid dissipation at the optimum operating current. Once these idiosyncrasies were discovered the semi-permanent testing facilities were set up as indicated in figure 4. Although this does not represent the ideal testing facility it provided adequate evidence of oscillations and made possible an investigation of the bandwidth and tube interchangeability. No precise power measurements were made in that relative power was



Test Facility For Prototype

Figure 4

considered adequate. A rough approximation however is that the power in milliwatts is equal to the measured crystal current in milliamps when using a type 1N23 crystal known to be in good condition. This approximation is based on a discussion with personnel at the Sylvania plant in Mountain View, California. Once oscillations were attained several crystals were tried and the one showing the highest output was used throughout the remainder of the experiments.

For the measurement of frequency the Signal Corps TS 117/GP was utilized, the dipole antenna giving excellent results. The leakage was such that sufficient signal could be picked up without disconnecting the probe from the cavity.

Data were taken on several tubes, the results of which are summarized in table 1. It will be noted that some tubes had a higher output than others. The reason for this anomaly is not known, but is is assumed that small differences in tube construction account for the major differences. The possibility of variations in tube insertion within the cavity was eliminated by the expedient of inserting the tube in the cavity several times and reproducing the data without variation.

It was decided that the effect of an axial magnetic field would be investigated using the lighthouse tube. This was accomplished easily in that all of the metal used in making metal to glass seals is Kovar which is a magnetic material. Utilizing this fact allowed the placing of a very concentrated magnetic field across the electron interaction space. An electro-magnet was constructed and the results of this experiment were negative in that the application of the magnetic field in any amount up to the maximum available reduced the strength of oscillations.

TABLE 1

Record power data from several 2C40 tubes.

Tube Number	Power Output
1.	.35 milliwatts
2.	1.70 milliwatts
3.	3.50 milliwatts
4.	1.00 milliwatts

The above power outputs represent the maximum that could be attained in each case.

For purposes of reproducing these and other data it is suggested that the below operating instructions be followed:

a) Set up equipment as shown in figure 4.

b) Turn on blower.

c) Set filament volts to about 3.4 volts. After the grid volts supply has been turned on the filament voltage may be varied in order to obtain the optimum output.

d) Apply grid voltage. Use a regulated supply for best results.

e) Lower filament voltage slowly in securing the equipment and turn blower off last. This securing procedure will minimize the breakage of lighthouse tubes.

CHAPTER III

The facilities at the Research and Development Laboratories of Varian Associates were made available to the author during the Industrial Tour for the purpose of attempting to construct a workable tube in the "K" band utilizing the principles already developed. This chapter is dedicated to the detailed description of the construction of this tube.

Every attempt was made to utilize existing sub assemblies or structures wherever possible in order to be able to complete a tube during the short stay at the Varian Associates. Several departures from the simple description offered in Chapter I were of necessity made, partly for the reason that unsound engineering principles were involved and partly because of the availability of the ready made cathode structures and ceramic rings.

The idea of having the emitting surface directly on the surface of the cavity turned out to be an impractical one for the reason that the heat conduction away from the coating would be so great that no emission would result. The means to circumvent this obvious defficiency was to place the cathode or emitting surface directly below the cavity and have the electrons pass into the cavity through a grid. This would necessitate making the cathode slightly negative with respect to the cavity in order to draw the electrons into the interaction space. The construction of the cathodes available made this readily accomplished.

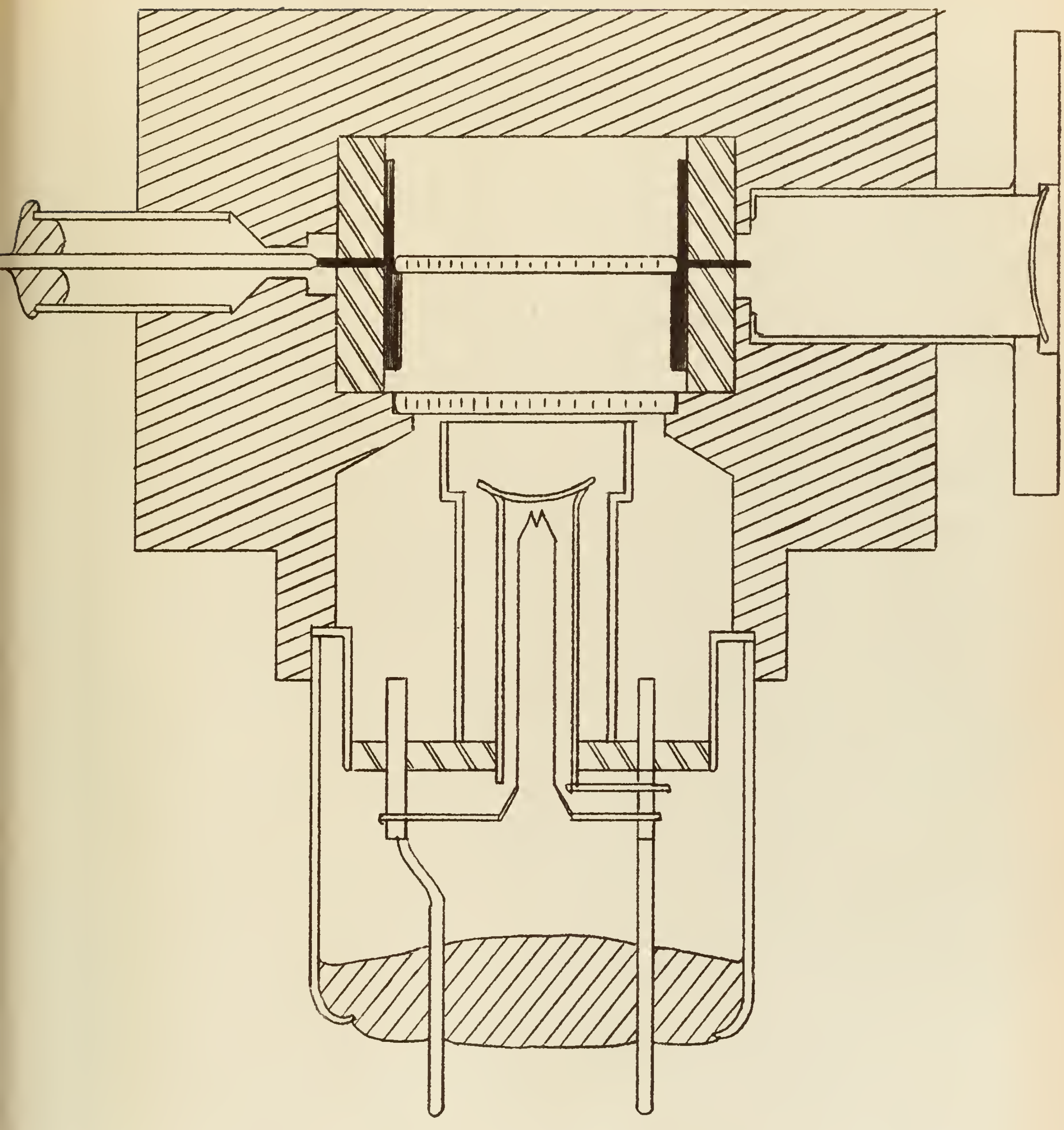
The only ceramic material of suitable shape available was in the form of short sections of cylinders. It was decided that two of these

sections would be used to form the insulation and support for the grid. The inclusion of lossy material of any form is regrettable, but no alternative was forseen at this time. The shape of these ceramic parts more or less determined the shape and frequency of the cavity. They also determined the extent of parabolic distribution of field that was attainable because of their length.

The grids used were of the tungsten ribbon type and were used because of their ability to withstand the heat caused by the electron beam.

Coupled with the above limitations was the desire to construct the tube in such a manner that would permit a minimum number of silver soldering processes. Toward this end a self jigging stacked structure was decided upon that would permit all joints to be soldered simultaneously in one transit of the hydrogen furnace. Shown in figure 5 is a cross section view drawn to five to one scale of the tube as finally constructed.

The first item to be constructed was the central grid support structure. This was done so that a cold test model could be constructed using the actual grid structure. A cold test model was deemed necessary for the purpose of determining the frequency of the desired mode of operation. This was of importance primarily for determining the size waveguide flange that would be used. The cold test model consisted simply of an exact full scale cavity with the exception that the lower grid, the coupling window, and the positive grid supply wire were omitted. Holes were drilled in the centers of the two halves of the cavity to accomodate two probes. The grid structure was then inserted and the two halves securely clamped together. A search was then made to find the transmission frequency.



Integrated Tube as Constructed

Figure 5

The lowest mode of transmission was found to be thirteen kilo-megacycles and this was assumed to be the correct mode of operation for the desired interaction within the cavity.

All parts to which a glass seal must be made were of necessity constructed of kovar, a metal having the same coefficient of expansion as glass. All other parts were constructed of oxygen-free copper to permit the axial magnetic field easy access and to prevent poisoning of the emitting surface during the baking out process.

Not shown in the figure is the junction of the two halves of the cavity. This occurs in the plane of the central grid. The only other details which were omitted are the evacuation tubulation and the getter.

The cathode is one of the standard Varian types used in one of their klystrons. The details of its construction are unimportant inasmuch as any source of electrons would have suited the purposes as long as it could provide sufficient current density. It was considered that the rated sixty millamperes of this cathode was sufficient. The cathode was inserted after the furnace solder because the glass seal in the cathode would not stand up under the melting temperature of the silver.

The only remaining steps to the completion of the tube were the glassing in of the mica window and the glass seal between the grid supply wire and the kovar tube. Once these steps were taken and a successful leak test made, the tube was evacuated and the cathode activated.

All attempts to make this tube oscillate resulted in failure. It is felt that this failure was due to insufficient coupling between the R-F field and the electron beam. Should time have permitted, another tube

would have been constructed making the cavity re-entrant. This would reduce the gap spacing and increase the beam coupling but would not permit shaping the grid to obtain the parabolic field distribution.

CHAPTER IV

The success of this oscillator, at least in the prototype, was gratifying. No great future for this device, at least in its present form, is forseen for it offers relatively few advantages over currently available microwave sources. Among these, however, are its electronic tuning range which proved to be in the order of two percent as contrasted with the usual one percent generally attained in klystrons. Another obvious advantage is the simplicity of construction, requiring simply a disk seal type tube and a simple external cavity easily turned on a lathe. Its low operating voltage might be an advantage in some applications.

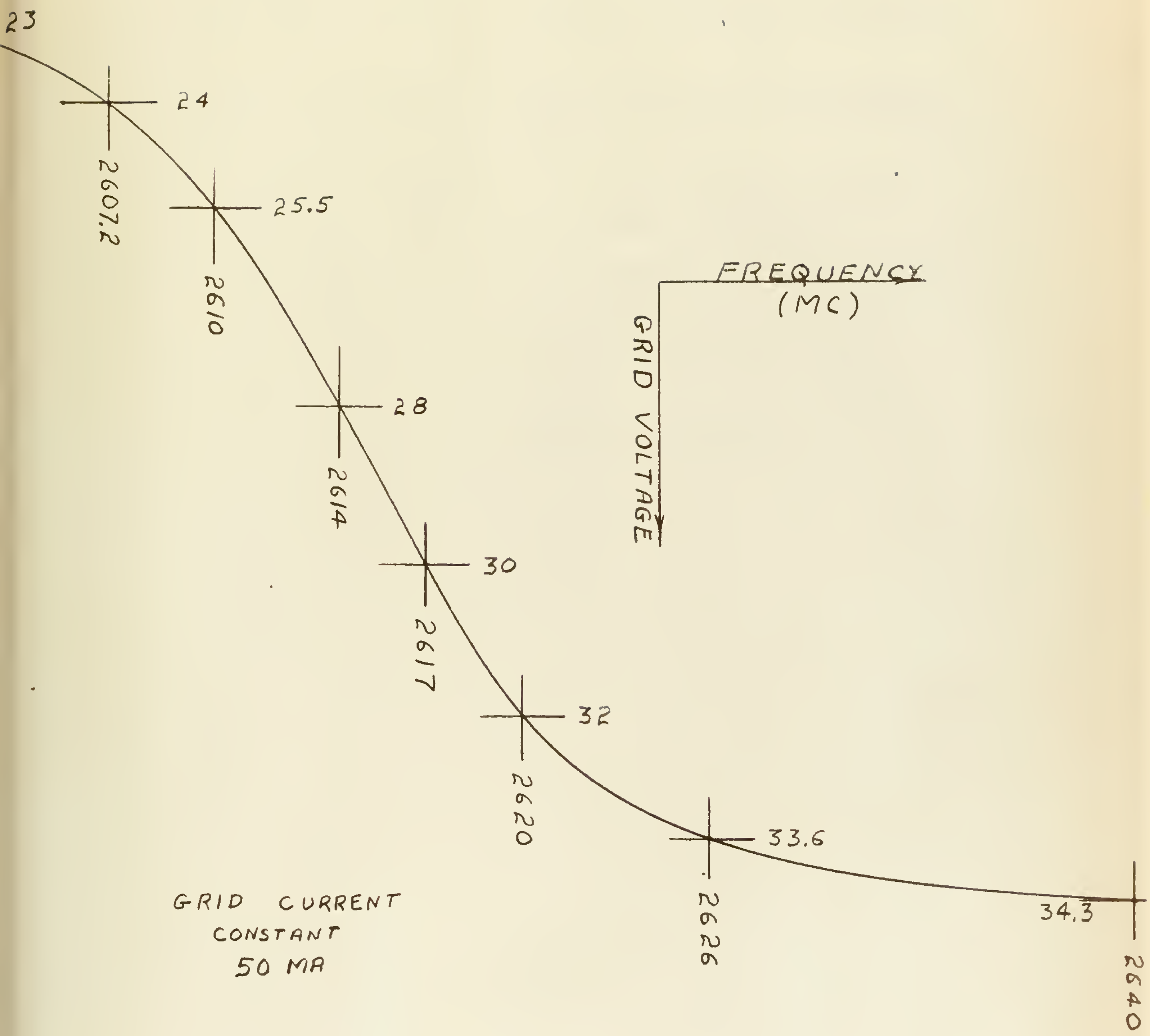
It is probable that the optimum operation has not been attained in this first try and that much higher output power and higher frequencies can be attained utilizing this same principle. In order to investigate the possibilities of other configurations a cavity having moveable anode and grid would have to be devised or build a number of fixed constant devices and investigate each thereby arriving at the optimum.

Working with this type of oscillations has brought to mind at least one other application which unfortunately time does not permit the investigation. It is proposed that an untuned amplifier may be constructed. The basic structure of this device would be a rectangular waveguide, basically as described in the first chapter of this paper, down which would be launched a wave in the TE_{01} mode. The voltage of the grid would then be adjusted such that oscillations did not exist but are on the verge of breaking into oscillation. As in the traveling wave tube there would

exist waves traveling in the opposite direction from those desired, but this difficulty could be circumvented as in the traveling wave by the judicious use of attenuation material. It is felt that such a device would have at least two advantages over the traveling wave tube: No magnetic field would be required and secondly, no slow wave structure would be required. No simple means of constructing such a device, using ready made electron mechanisms as was done in the case of the oscillator described herein, appears readily available. For those interested in the investigation of this proposed phenomenon it is suggested that the experiment described below be performed as a starting place.

Build a section of vacuum tight demountable wave guide with entrance and exit probes. Provide a central grid structure, possibly consisting of several wires stretched longitudinally or even a single wire. For the electron source, it is suggested that a single wire of tungsten, coated to give it ample emission, be supported a short distance above the center of one face of the guide. This would provide the electron action in the proper plane for interaction with the desired mode of operation. No attempt will be made here to guess where the absorbent material should be placed except that most certainly an absorbent termination should be placed at the launching or entrance end.

One factor that prompts the prediction for the success of such a device is its similarity to the familiar regenerative receiver.



Plot of Electronic Tuning Range of Prototype

Figure 6

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